Towards an Operational Sectorisation based on Deterministic and Stochastic Partitioning Algorithms

Application to the French airspace LFEE (Reims)

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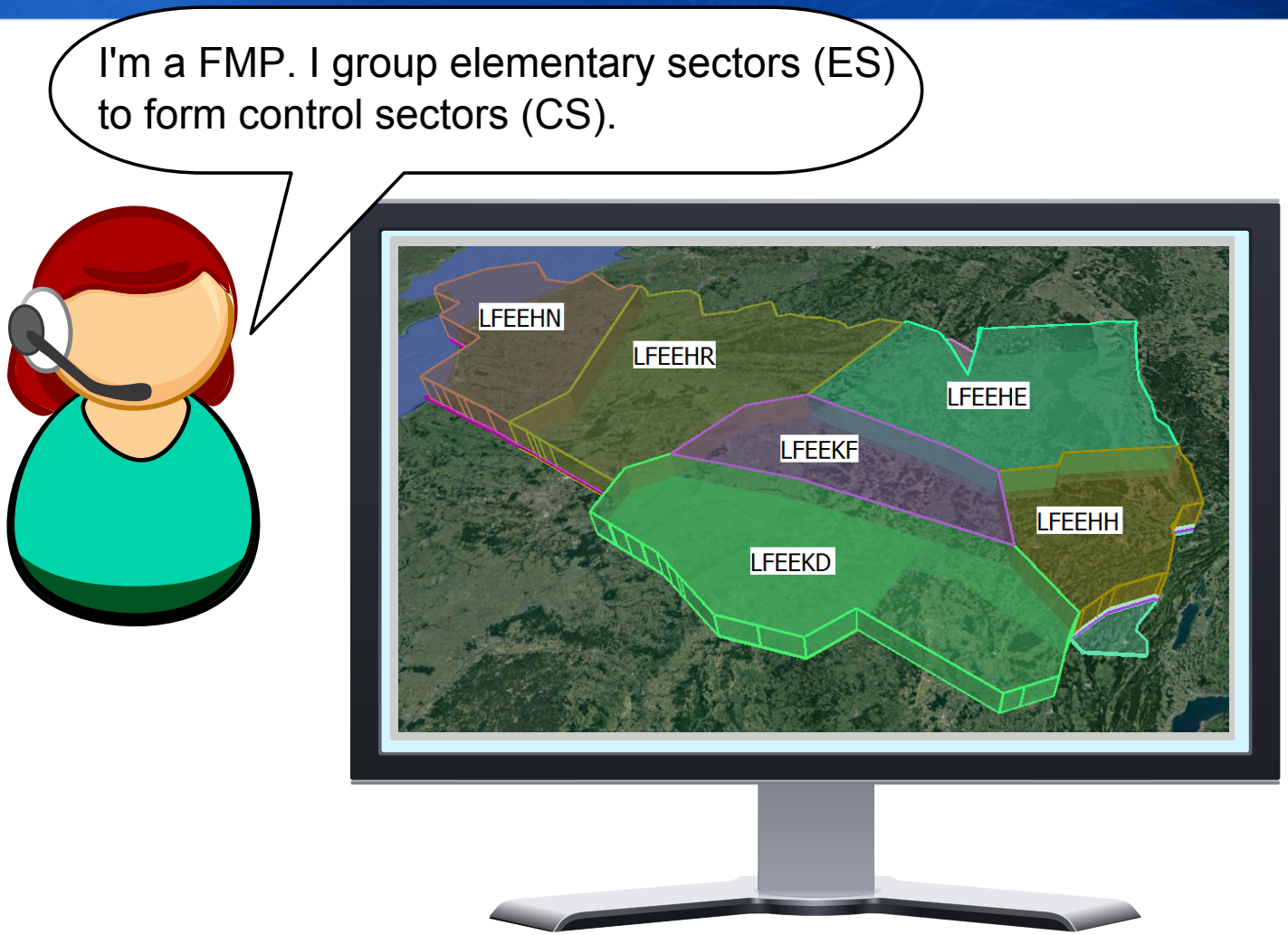
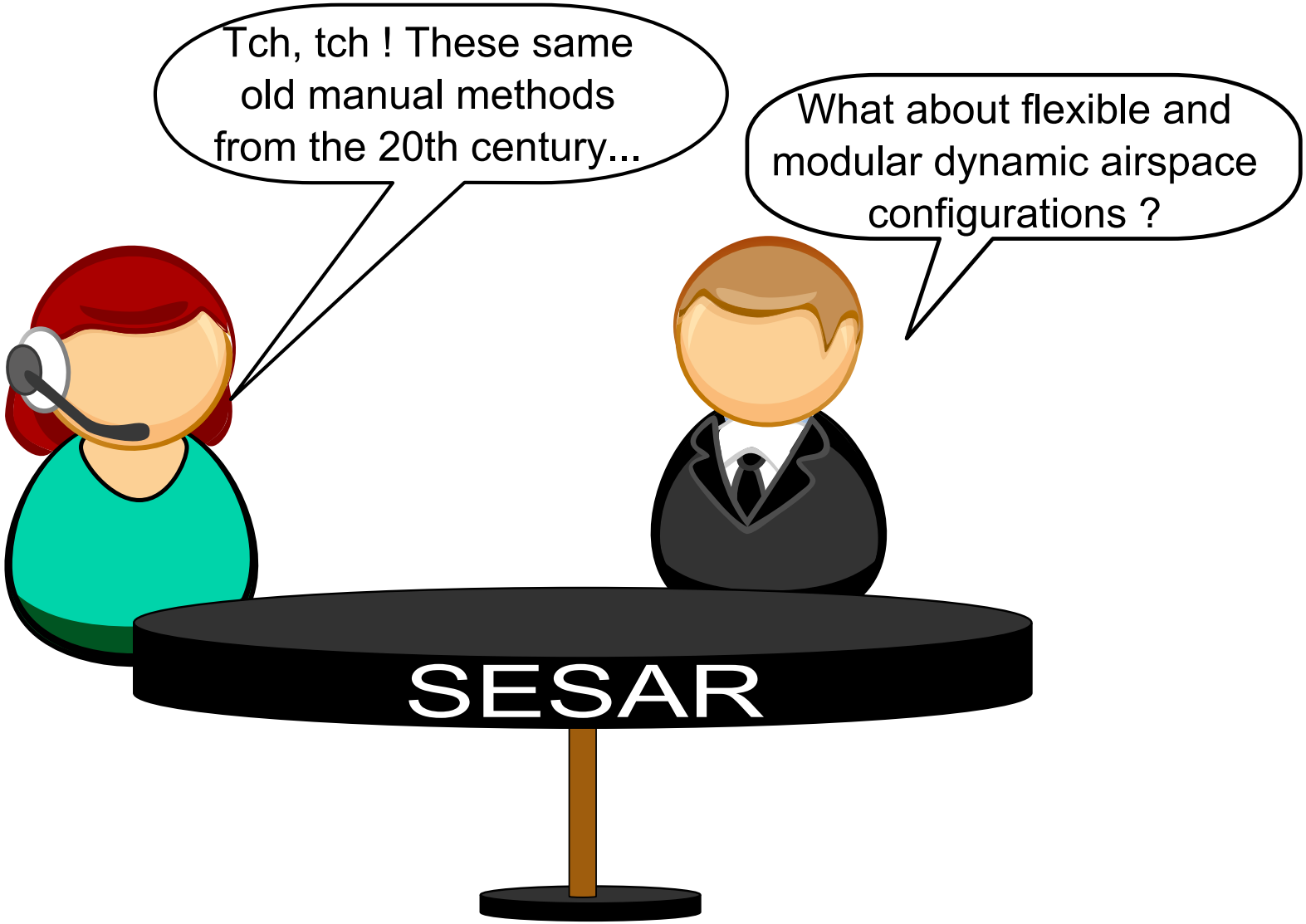
Sectorisation problem

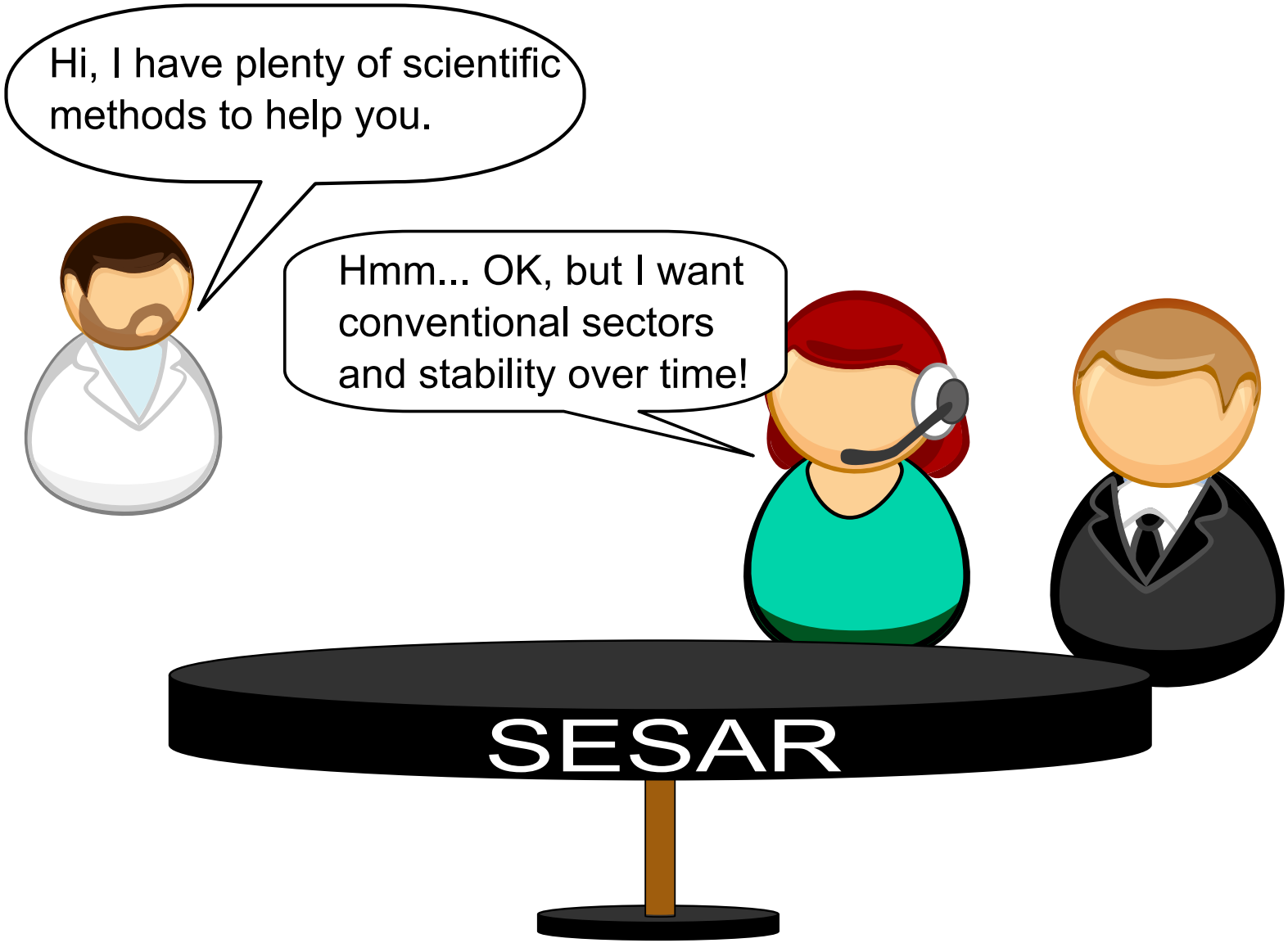


- FMP: Flow Management Position
- From Short-Term Planning to Pre-Tactical
- Sector configuration = set of CS for a given period of time.

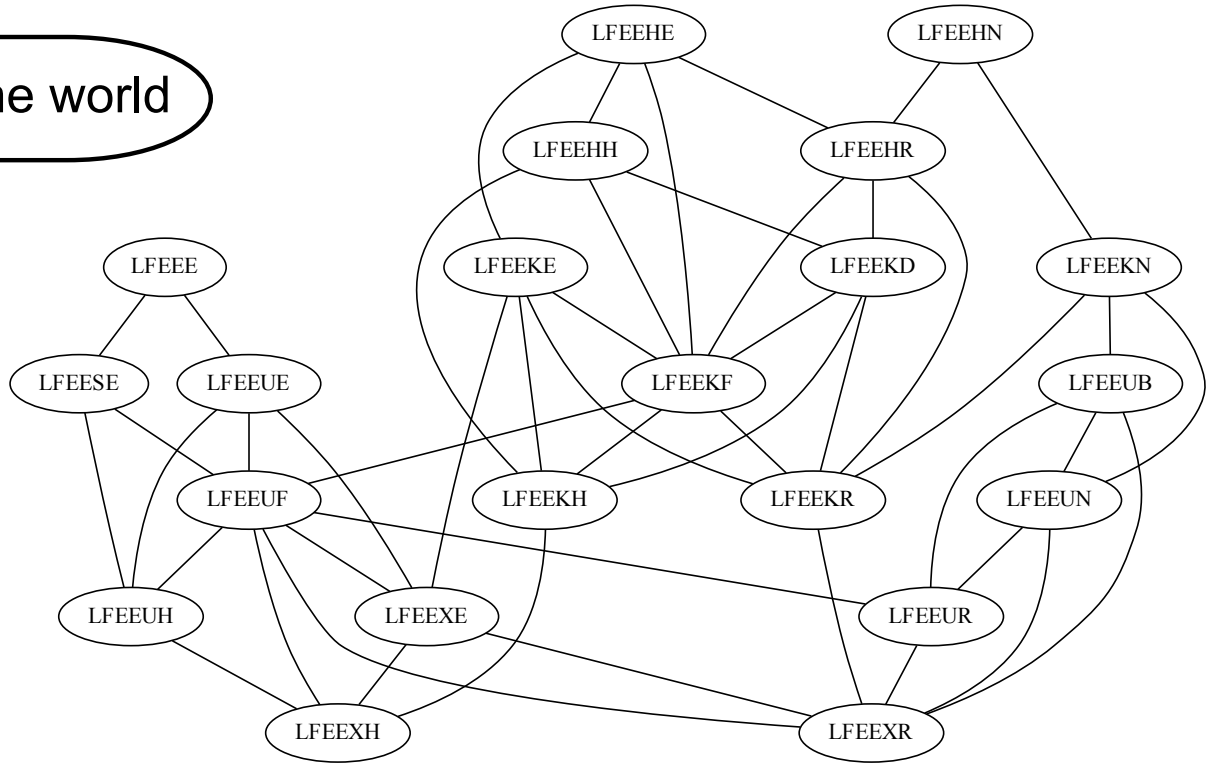
Motivation



Ambitions

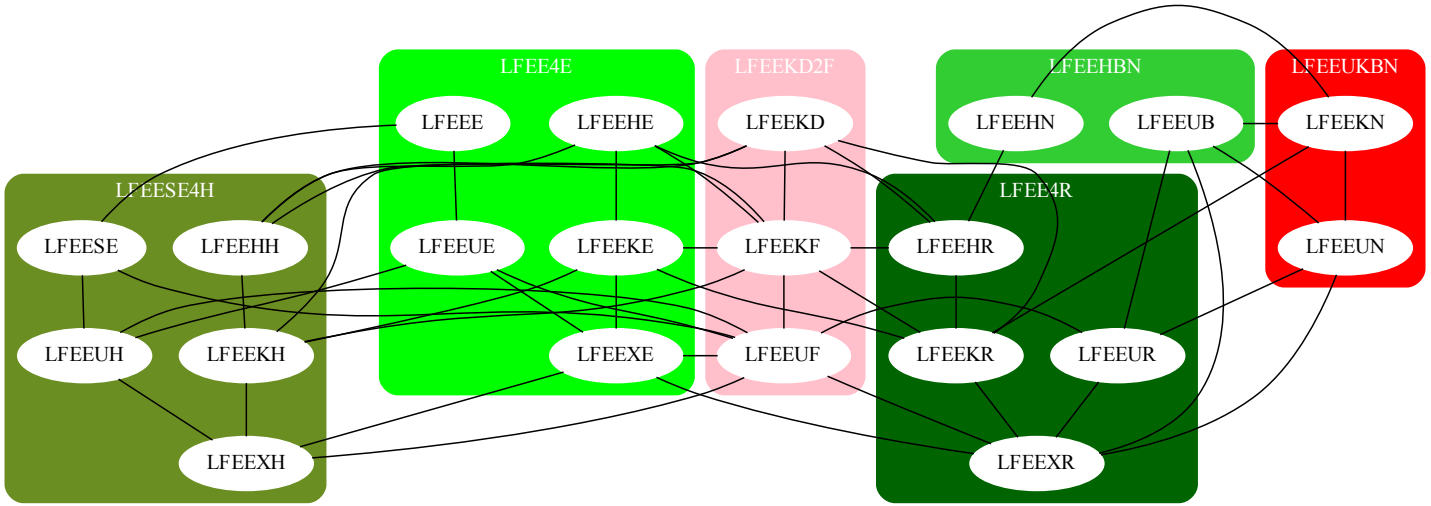


Model - Graph $G = (V, E)$



- V the set the building blocks
- E the set of edges (direct trajectories between two blocks)
- $D_v(\delta t)$ density for vertex v during δt
- $C_e(\delta t)$ coordination for edge e during δt

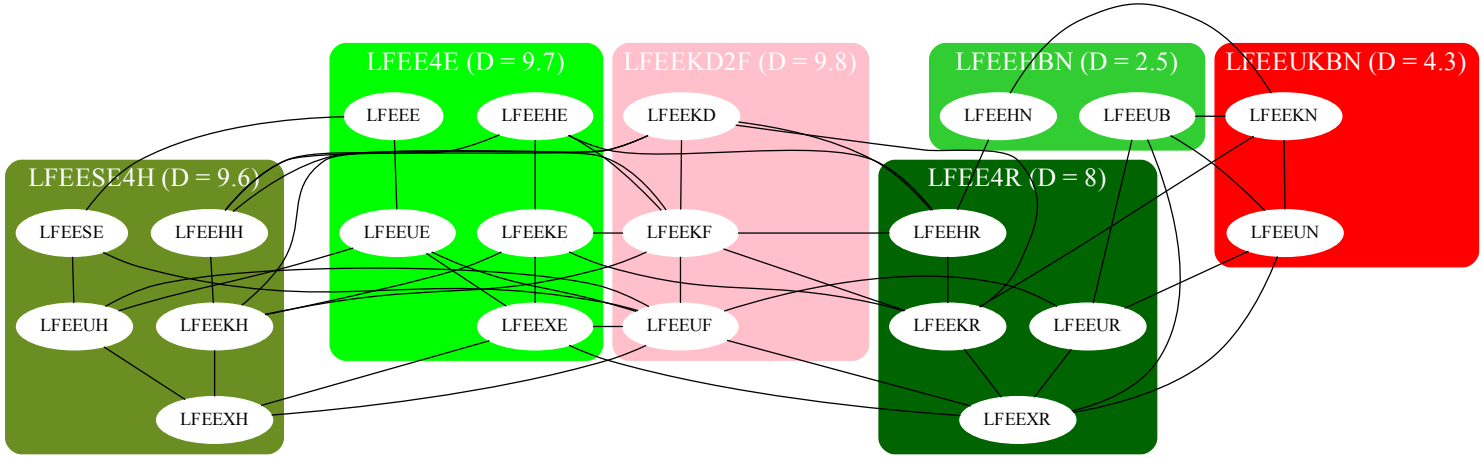
Partition and constraints



$$P_k(\delta t) = S_1, ..., S_k$$
$$S_1 = LFEEHBN = \{LFEEUB, LFEEHN\}, S_2 \quad = ...$$

- $\forall i \in 1, ..., k, S_i \neq \emptyset$
- $\forall i, j \in 1, ..., k, i \neq j, S_i \cap S_j = \emptyset$
- $\cup_{i \in 1,...,k} S_i = E$
- $\forall i \in 1, ...k, S_i$ satisfies the *connectivity* constraint

Balance objective



Definition

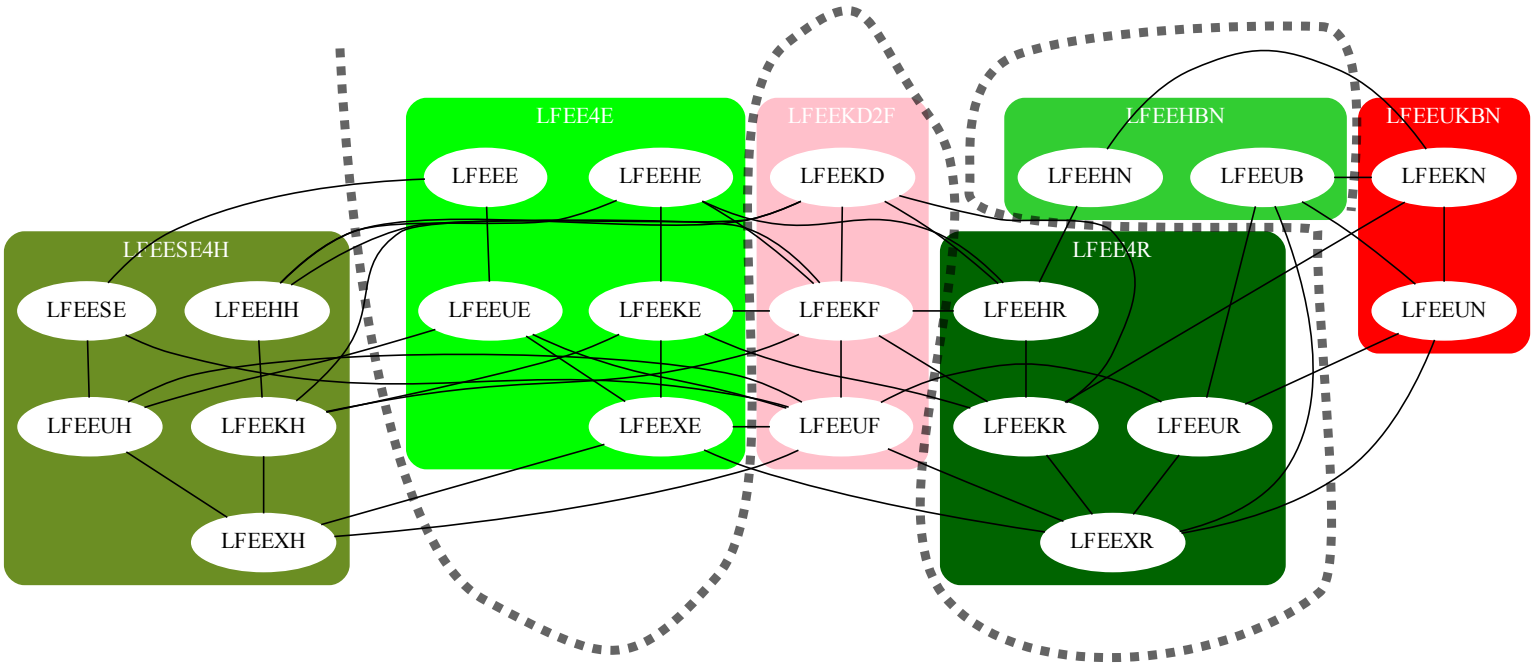
$$\text{balance}(P_k(\delta t)) = \sum_i \left| D_{S_i}(\delta t) - \frac{\sum_i D_{S_i}(\delta t)}{k} \right|$$

$$\text{where } D_{S_i}(\delta t) = \sum_{v \in S_i} D_v(\delta t)$$

$$\frac{\sum_i D_{S_i}(\delta t)}{k} = 7.3$$

$$\text{balance}(P_6) = 15.7$$

Cut objective

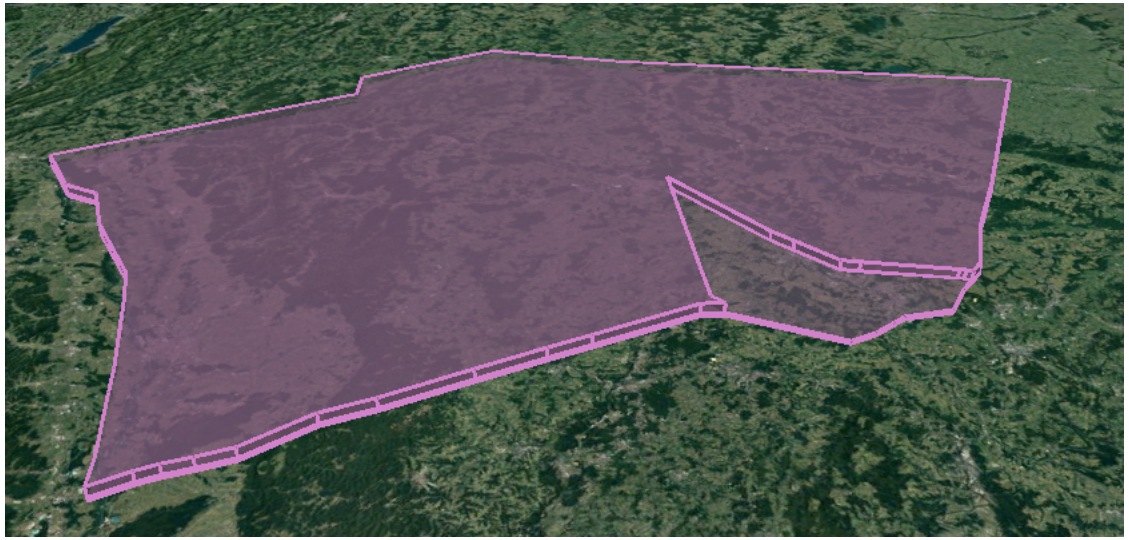


Definition

$$\mathrm{cut}(P_k(\delta t)) = \sum_{i<j} \mathrm{cut}(\delta t, S_i, S_j)$$

$$\text{where } \mathrm{cut}(\delta t, S_i, S_j) = \sum_{v_1 \in S_i, v_2 \in S_j} C_{(v_1,v_2)}(\delta t)$$

Compactness objective



Definition

$$\text{compactness}(P_k(\delta t)) = \prod_i \text{compactness}(S_i)$$

where $\text{compactness}(S_i) = \dfrac{\sum_{j \text{ prisms of } S_i} \text{volume}(j)}{\text{volume}(\text{cover}(i) \cap ACC)}$

cover(i) is the smallest prism which includes all the prisms of i

Other objectives that may be considered

- the total number of re-entries
- the total number of short transits
- the total number of overloads
- ...

Determining all conventional solutions

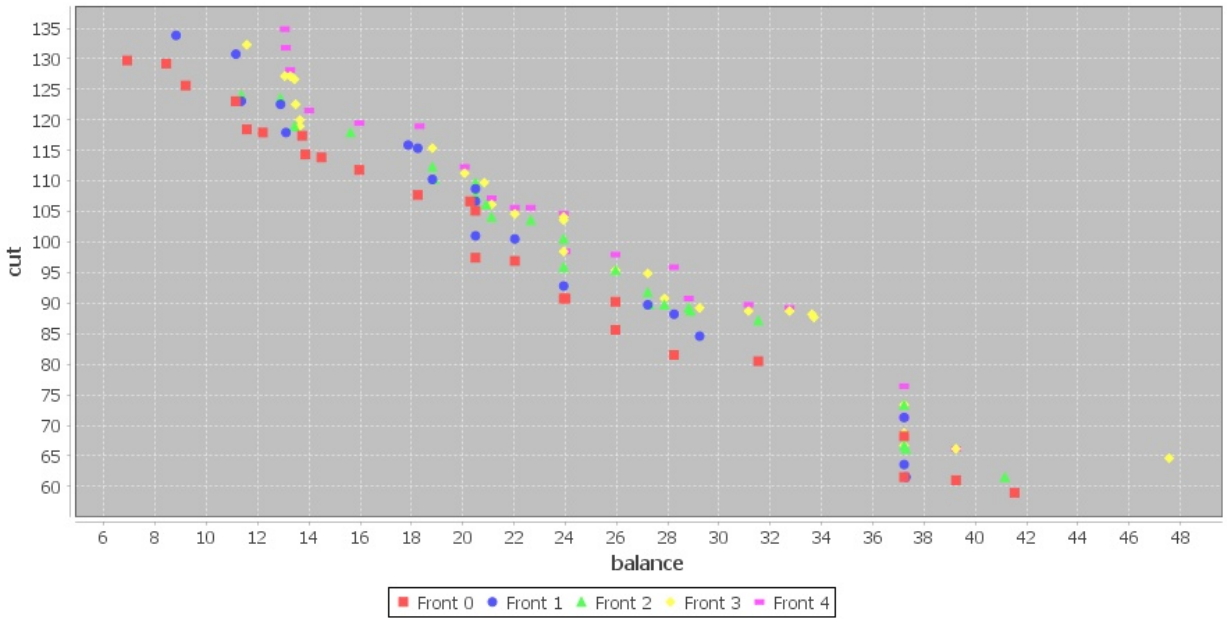
Exhaustive search tree

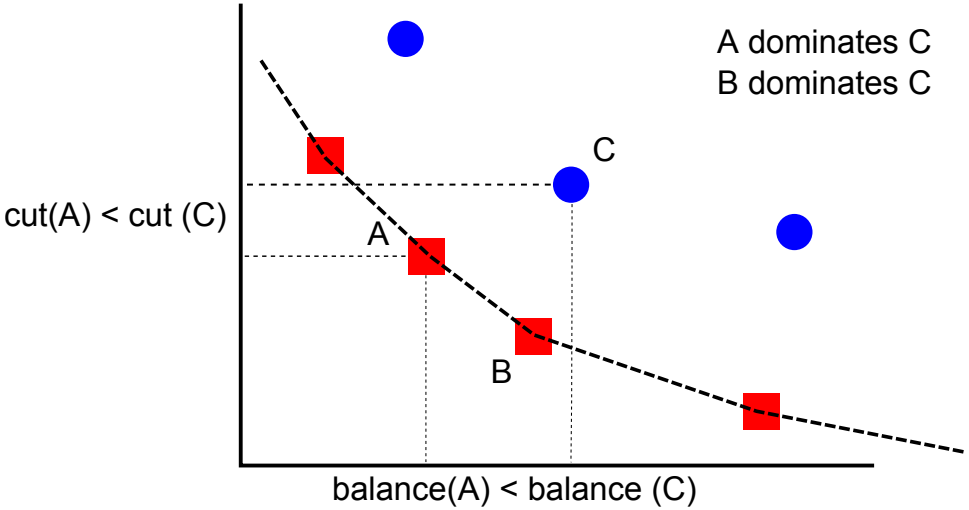
- Combining conventional sectors
- Use of cut rules to rapidly explore the tree
  - $\exists i, j \in 1, ..., k, S_i \cap S_j \neq \emptyset$
  - $\cup_{i \in 1,...,k} S_i = E$
  - Remaining nodes will not ensure $\cup_{i \in 1,...,k} S_i = E$

Applications

- Reims (LFEE) - 21 ES - 58 CS - 17 positions - 1.8×10^5 conventional sector configurations / 4.7×10^{14}
- Brest (LFRR) - 32 ES - 114 CS - 18 positions - 1.9×10^8 conventional sector configurations / 1.3×10^{26}

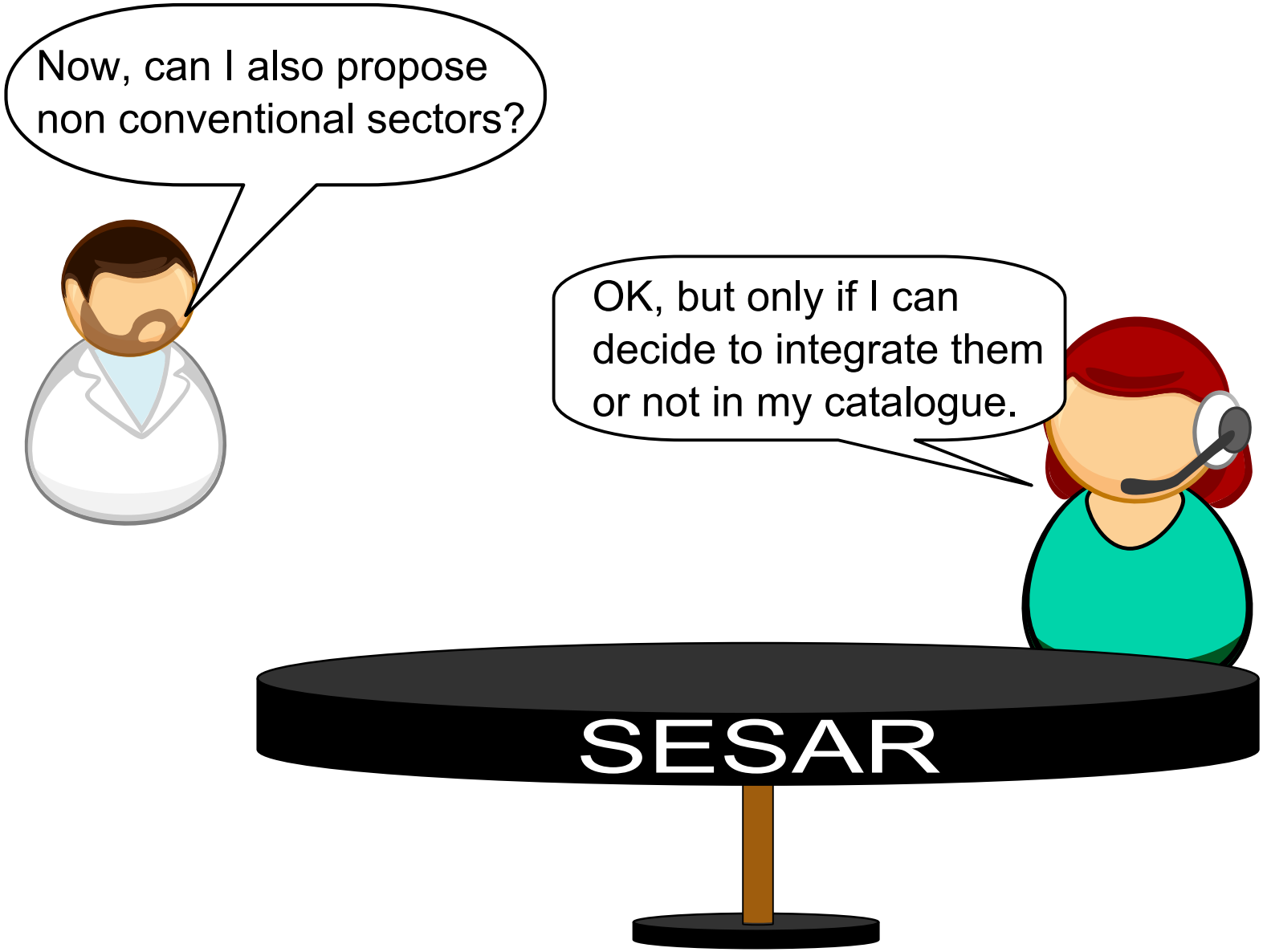
Assessing configurations - Pareto-optimal solutions





We keep solutions from the first Pareto fronts.

Refining



Simulated Annealing optimisation

Disorganising

$$\min \left(\alpha \mathrm{cut}(P_k) + \beta \mathrm{balance}(P_k) + \frac{1}{\mathrm{compactness}^2(P_k)} \right)$$

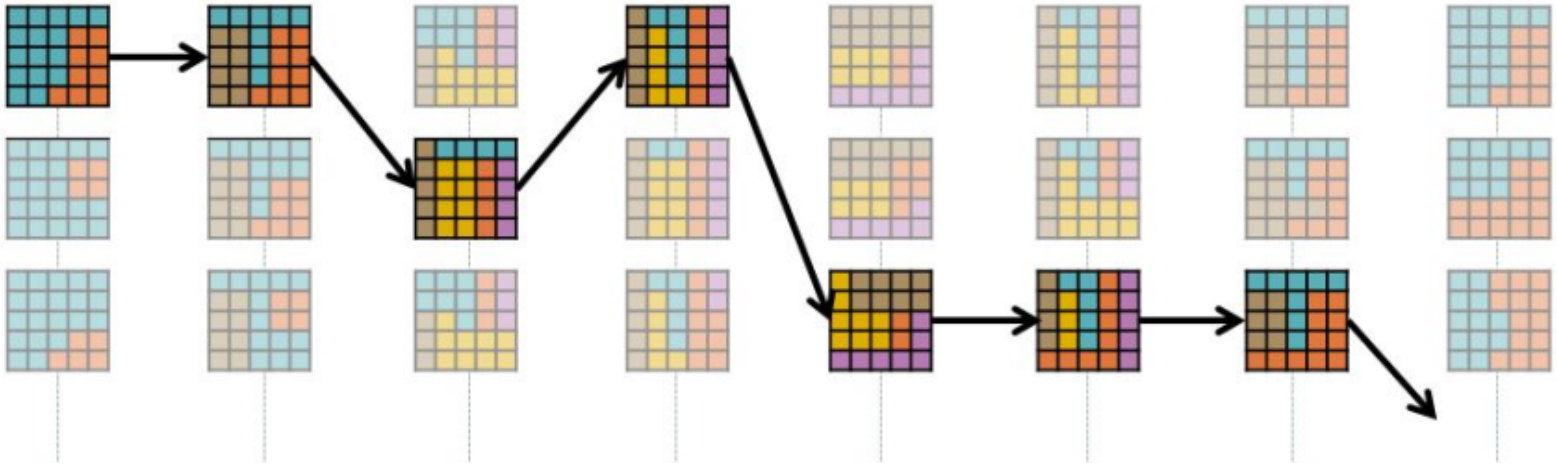
Reforming

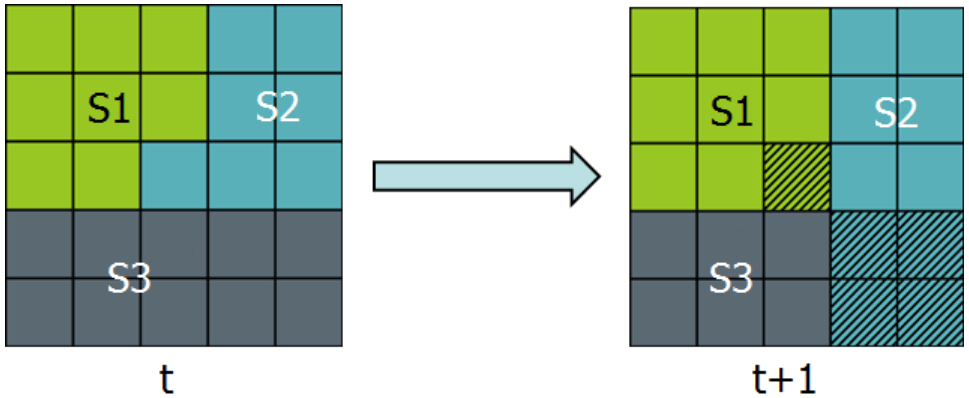
$$\min \ (1/\mathrm{compactness}(P_k))$$

$$\text{such that } \mathrm{balance}(P_k) \leq \mathrm{balance}(P_k^{initial})$$

$$\mathrm{cut}(P_k) \leq \mathrm{cut}(P_k^{initial})$$

Stabilising over time

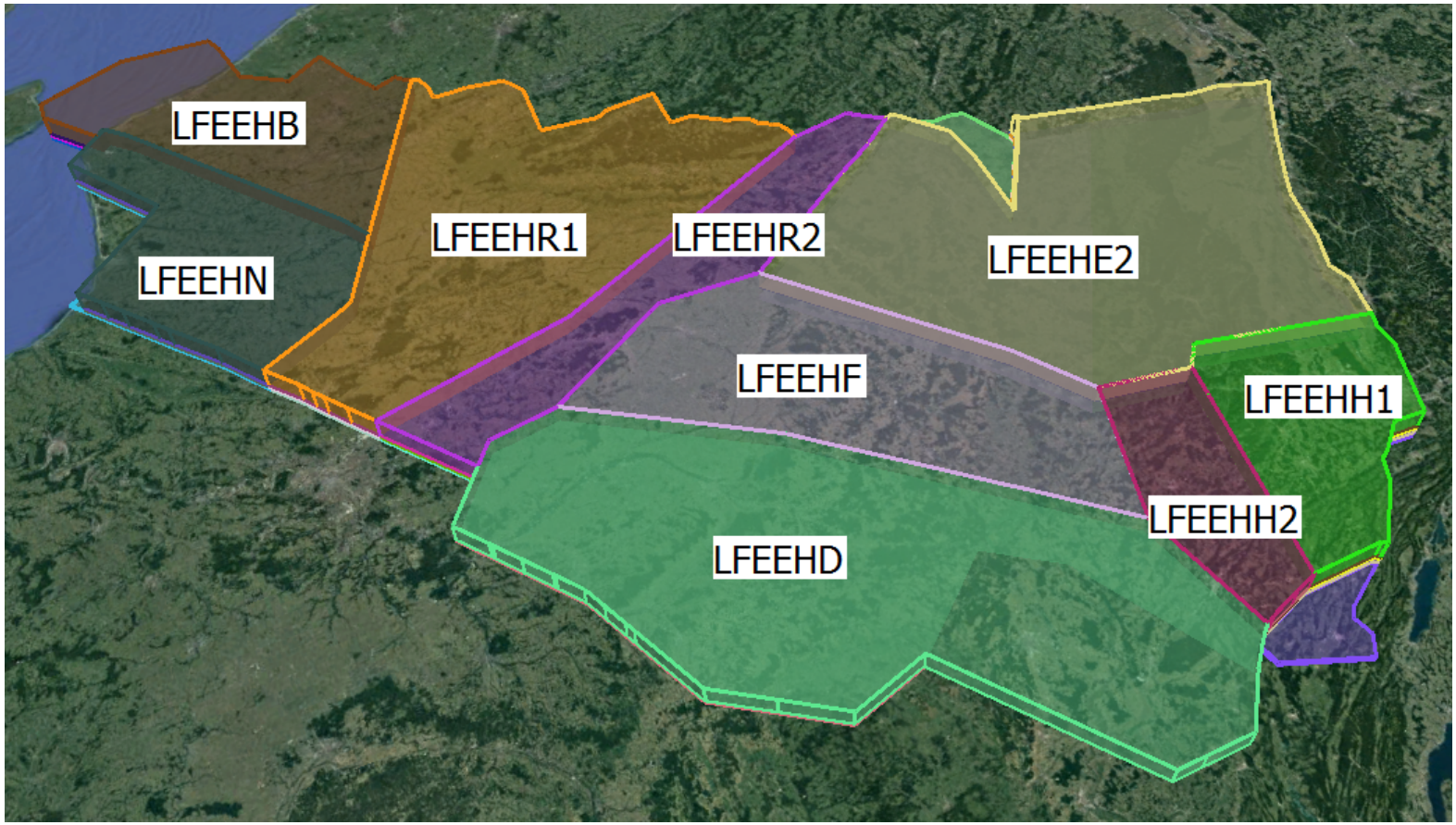




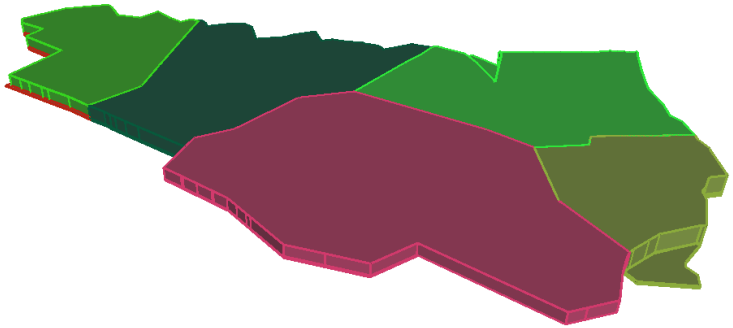
And we favor collapsing / decollapsing operations.

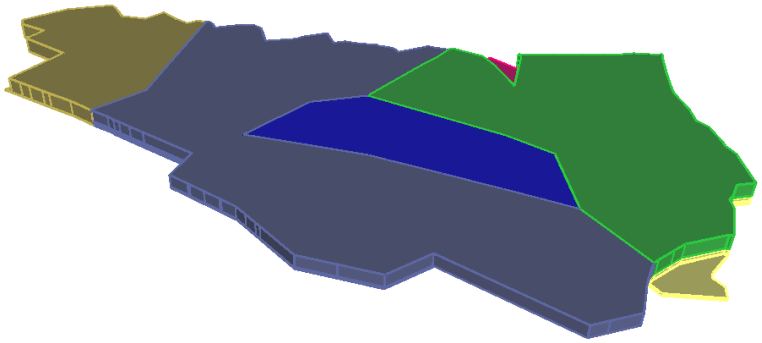
Scenario

Comparison to the sector configuration plan of a very busy day of traffic (2015, June 26th).



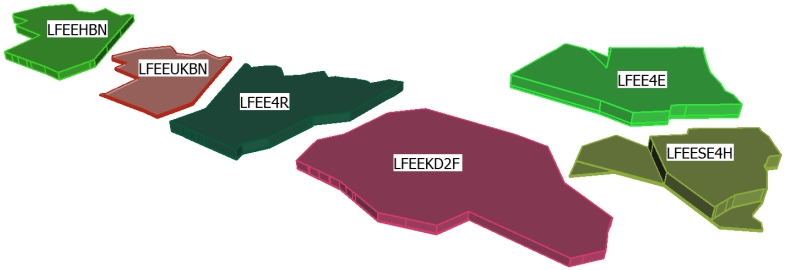
An initial solution and its refinement

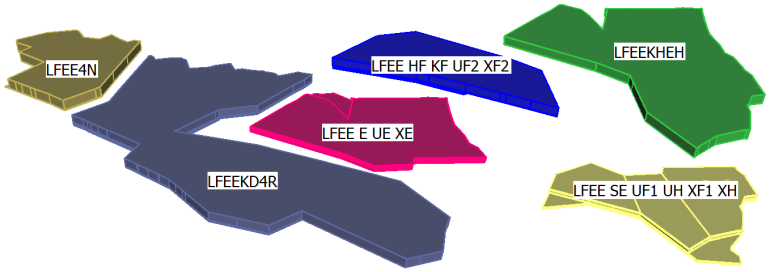




Conventional sector configuration

Refined sector configuration

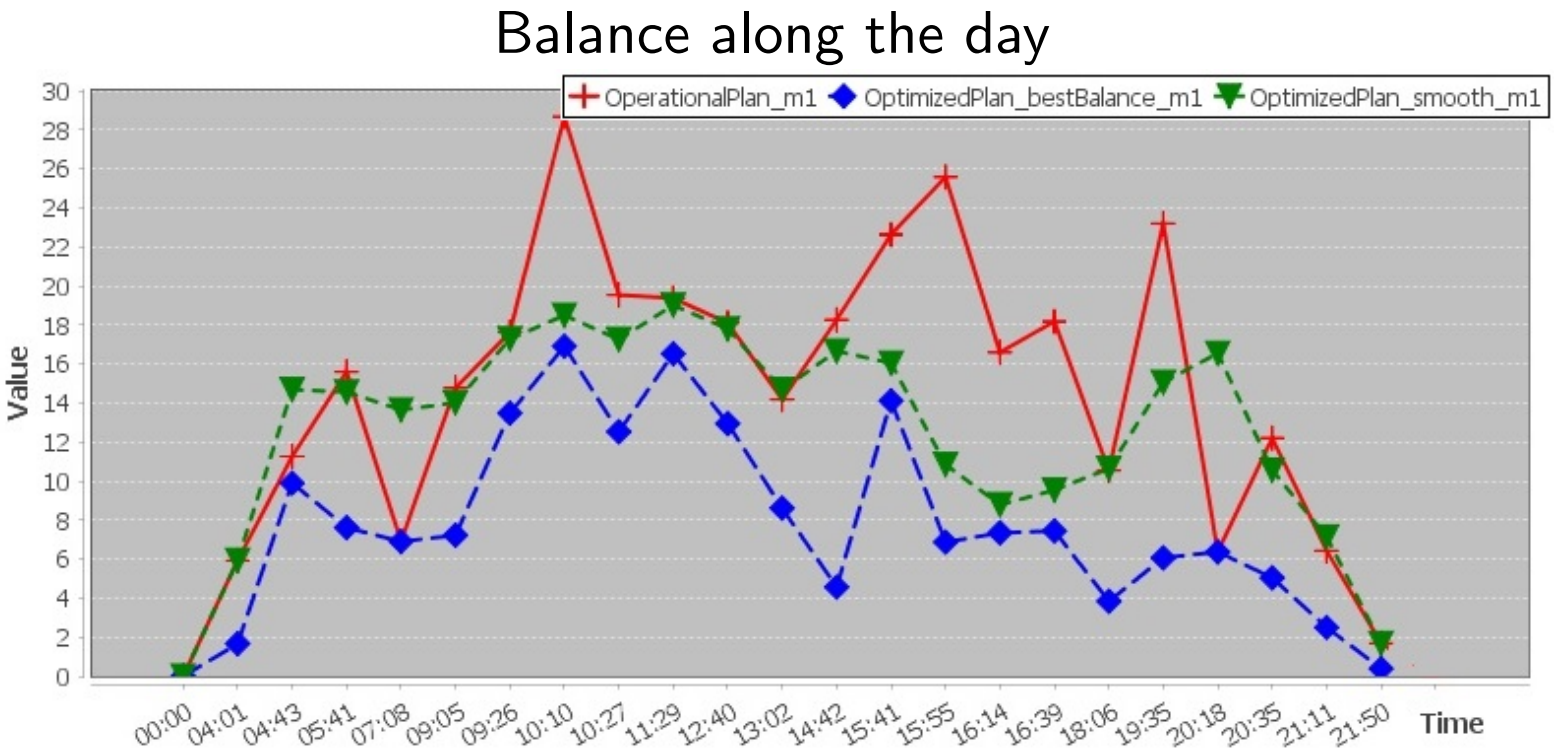




Balance: 16.02 $\rightarrow$ 8.434

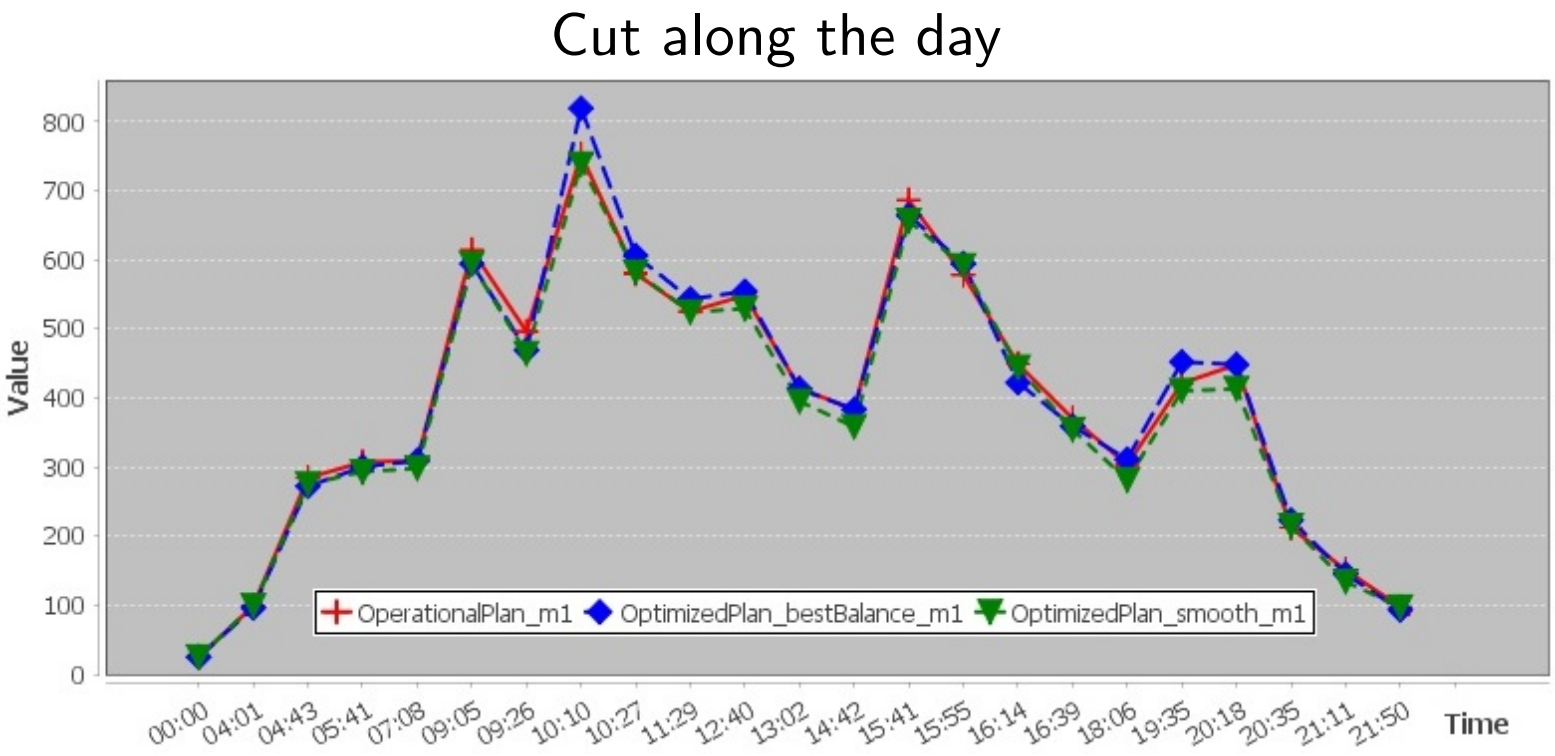
Cut: 121.03 $\rightarrow$ 111.28

Balance along the day



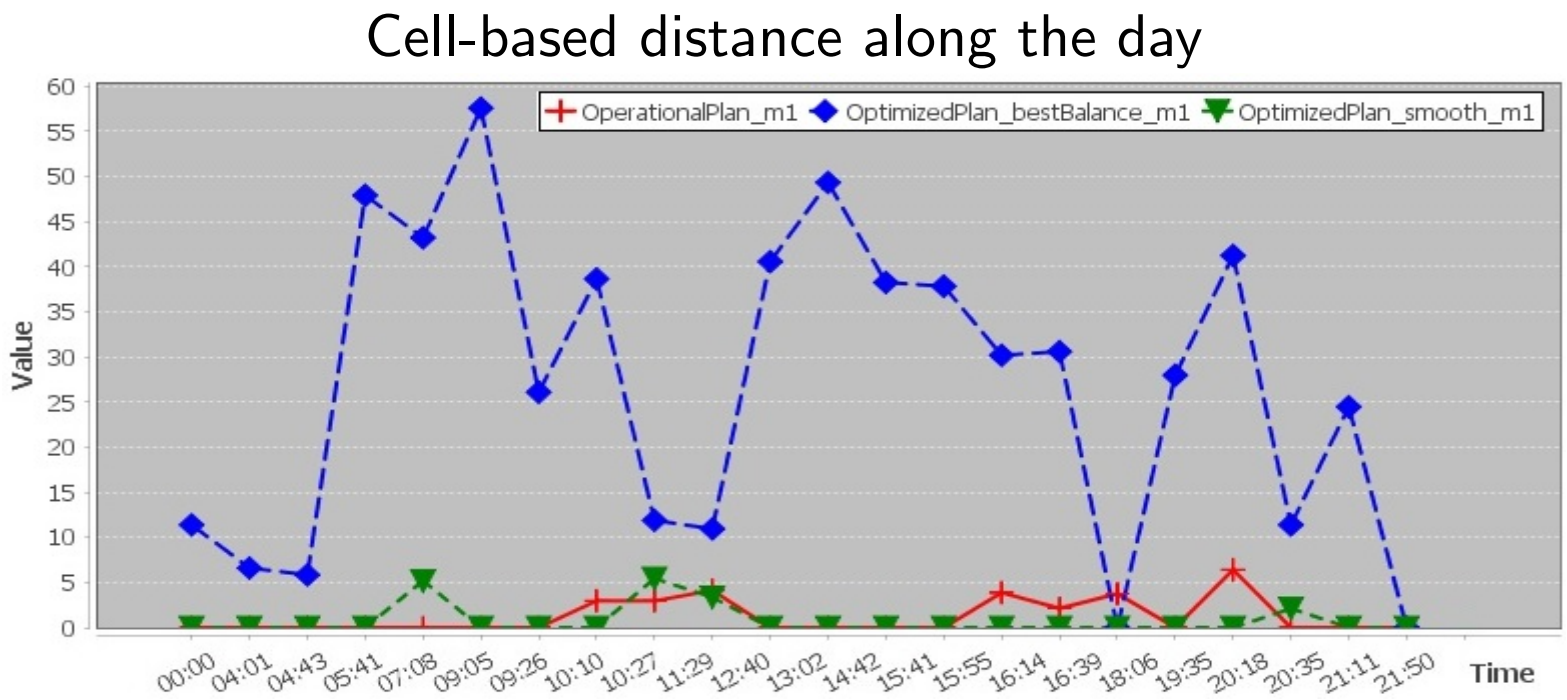
- Average gain : 12.9%

Cut along the day



- Average gain : 3.4%

Cell-based distance along the day



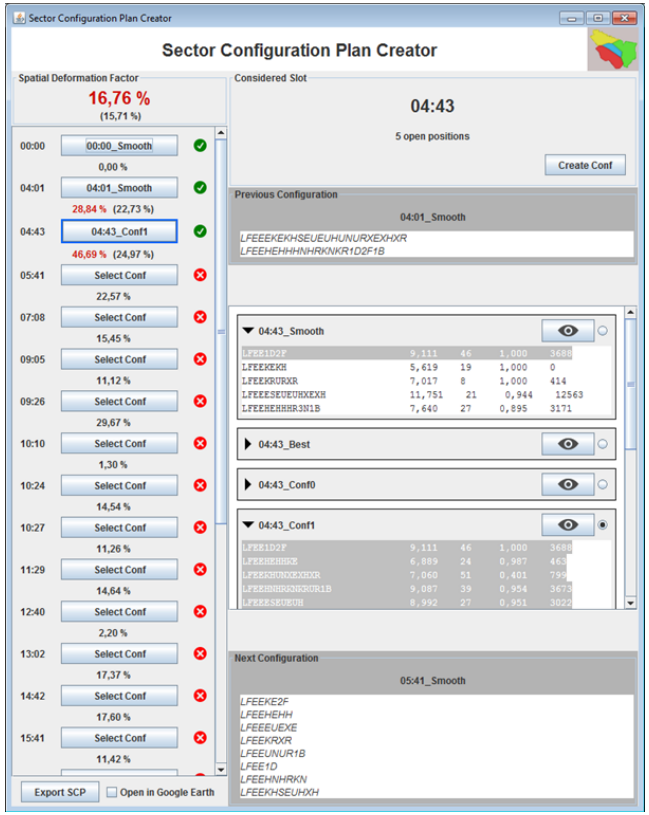
Conclusion and perspectives

- We can improve the workload distribution while
  - keeping compact sectors
  - ensuring stability over time

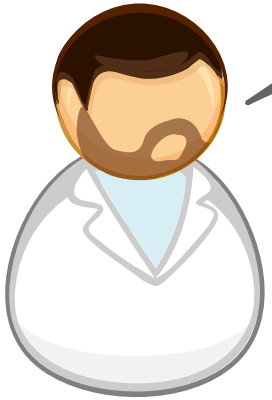
▶ Integrated to a decision support tool

Perspectives:

- Improving objectives such as
  - workload distribution
  - overloads
- Determining the opening times
- Increasing the number of blocks
- Using multi-objective techniques to refine



Questions ?



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